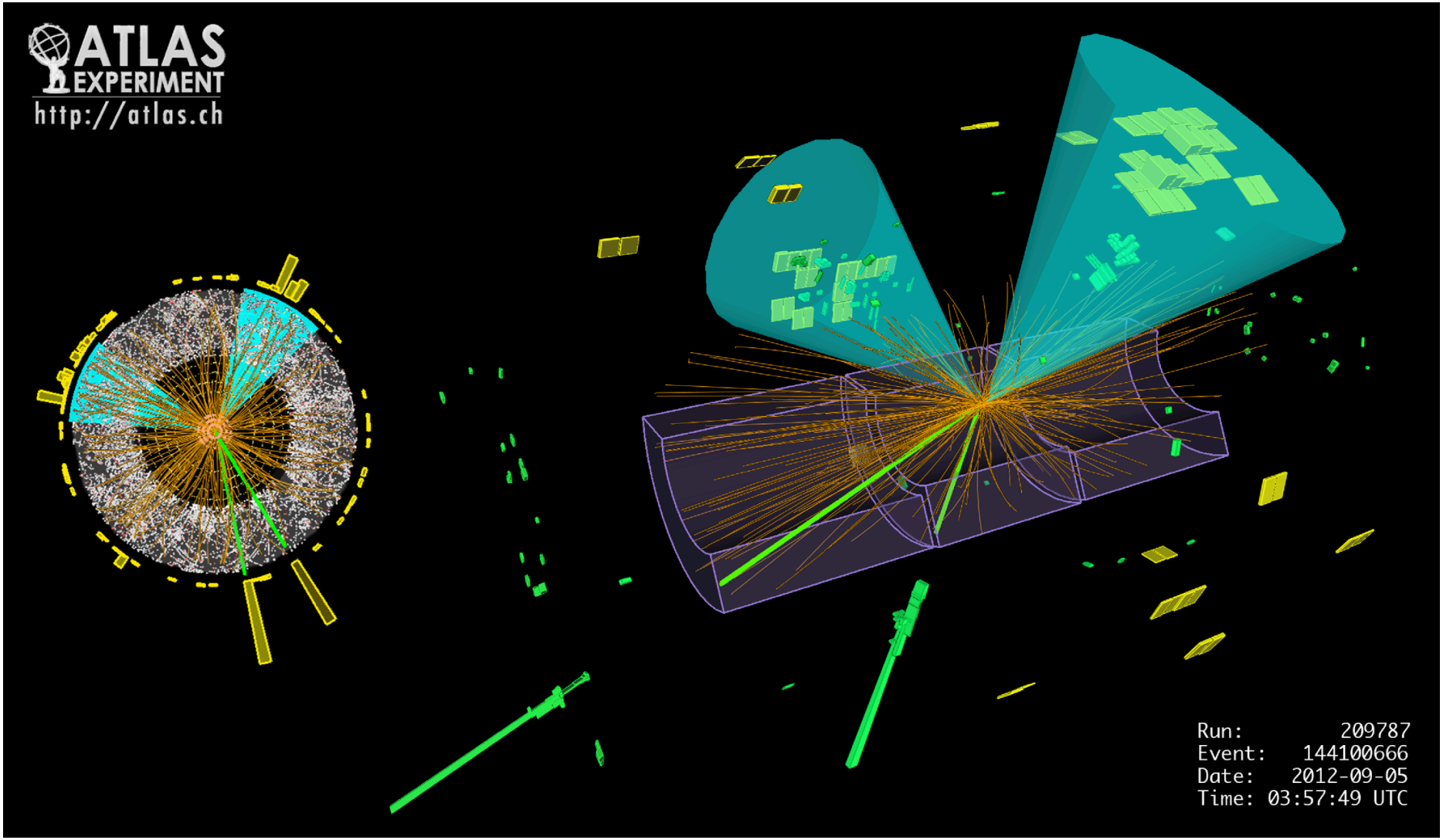
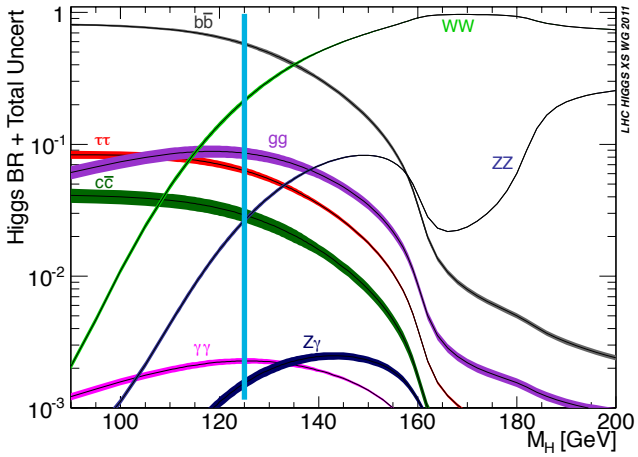


Search for SM H→bb decays with ATLAS

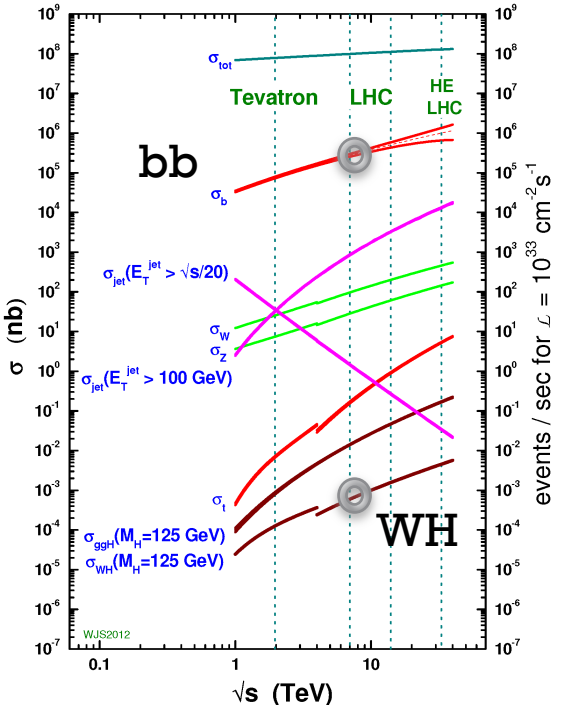
Stephan Hageböck
04.12.2012

universitätbonn

Searching the Higgs with b-Jets



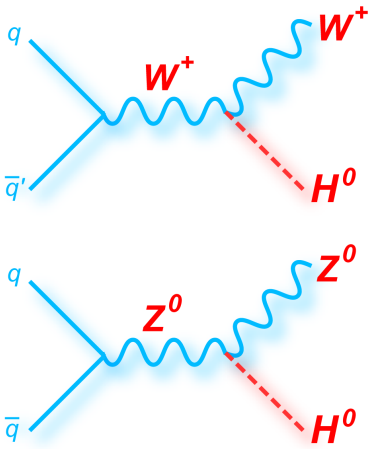
- Test if new particle is compatible with Higgs-Boson
  - bb: most prevalent decay (~ 58%)
  - Coupling to fermions
- Input for measurement of VH coupling

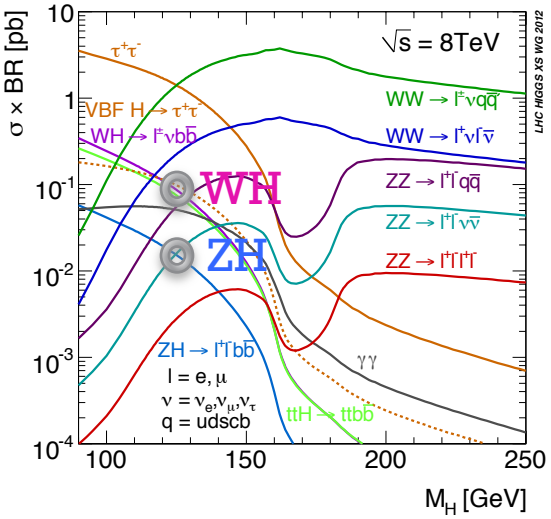


- b-jet background ~ 8 orders of magnitude larger
- Clean leptonic signatures in associated Higgs production
- This talk: Cut analysis for HCP 2012
  ATLAS-CONF-2012-161

Search Strategy

- Associated production
- Cuts for all channels:
  - 2-3 jets:
    1st jet pt > 45 GeV
    other jets pt > 20 GeV
  - 2 b-jets: 70% efficiency





- WH →lvbb
  - Exactly 1 lepton
  - MET > 25 GeV
  - 40 < MTW < 120 GeV
  - Single lepton trigger

- ZH → llbb
  - Exactly 2 leptons
  - MET < 60 GeV
  - 83 < mZ < 99 GeV
  - Single + di-lepton triggers

- ZH → vvbb
  - No lepton
  - MET > 120 GeV
  - MET Triggers

How to find the Higgs

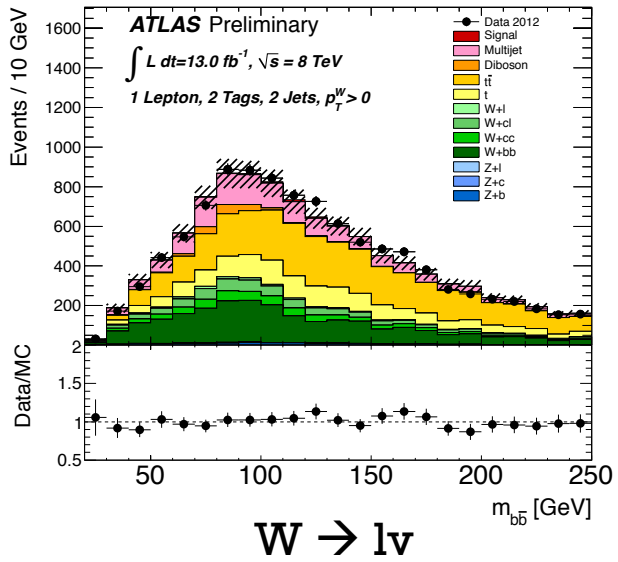
- Blinded Analysis
- Data:
  2011: 4.7 fb^{-1} (7 TeV) 2012: 13 fb^{-1} (8 TeV)
- Improvements in sensitivity:
  - S/B improves with high p_T^{bb}
  - 0 lepton: MET [120-160] [160-200] [>200] GeV (2 jets, 3 jets)
  - 1 & 2 lepton: $p_T^{W/Z}$ [0-50] [50-100] [100-150] [150-200] [>200] GeV
  - → 16 signal categories
  - Topological cuts refined separately in bins of $p_T^{W/Z}$
- Mass resolution for b-jets
  - Muons from semileptonic decays added to jets
  - Momentum corrections
  - b-tagging calibration from tt measurements:
    reduced systematic uncertainties for high p_T

Backgrounds

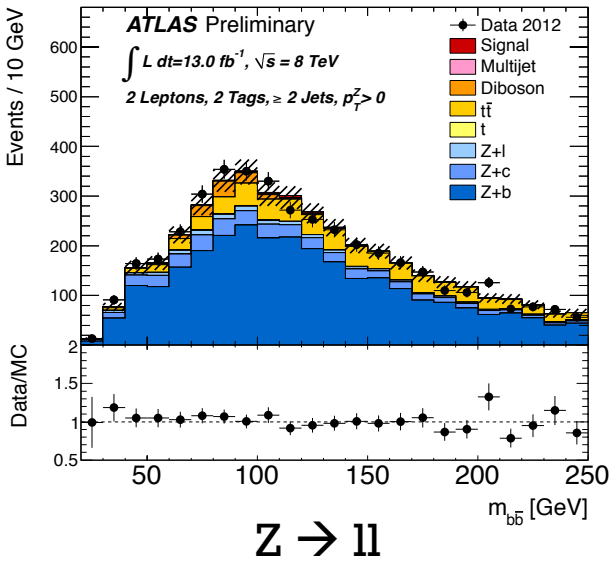
Data 2012
Signal
Multijet
Diboson
$t\bar{t}$
t
W+l
W+cl
W+cc
W+bb
Z+l
Z+c
Z+b

- Multi-jet background: Estimated from data (reversed lepton isolation)
- WZ,ZZ from simulation
- Other backgrounds: Shape: MC simulation Normalisation: Flavour fit to data

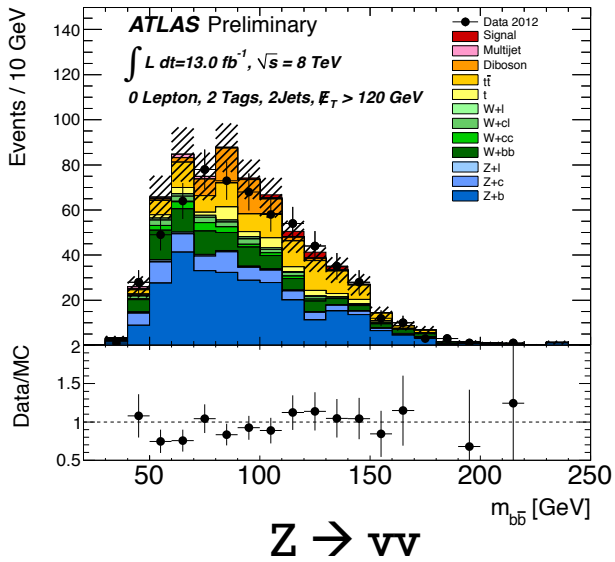
Signal:	WH/ZH Pythia8
Diboson	WW/WZ/ZZ Herwig
Multijet:	Data driven
Ttbar:	MC@NLO
Single Top	Acer/MC@NLO
W+b	Powheg
W+c/light-jets	Alpgen
Z+ b/c/light-jets	Alpgen/Sherpa



W → lν



Z → ll

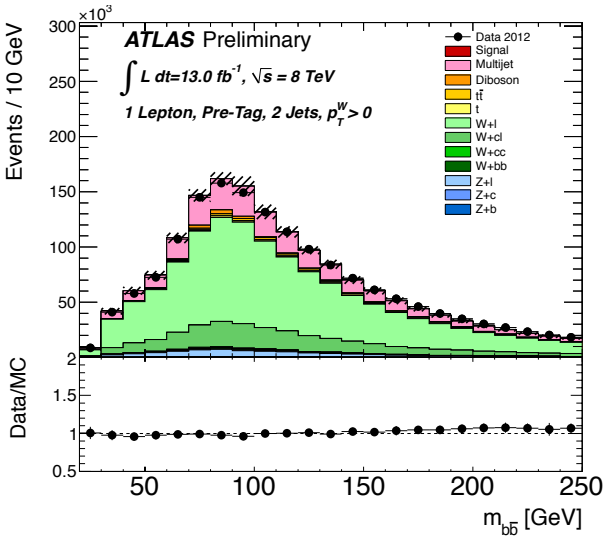


Z → νν

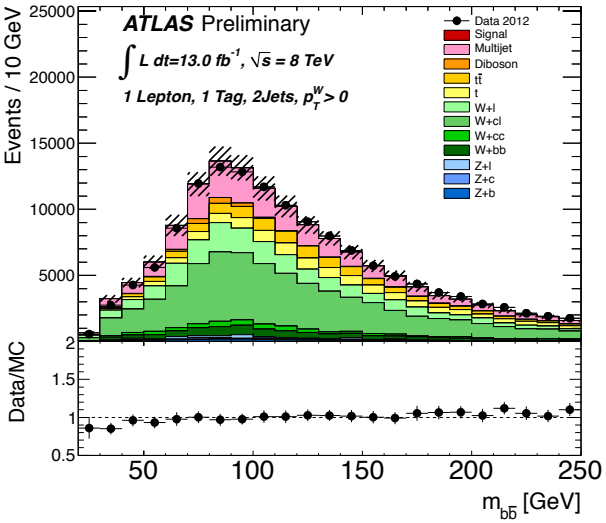
Example: Flavour Fit (1 Lepton)

Data 2012
Signal
Multijet
Diboson
$t\bar{t}$
t
W+l
W+cl
W+cc
W+bb
Z+l
Z+c
Z+b

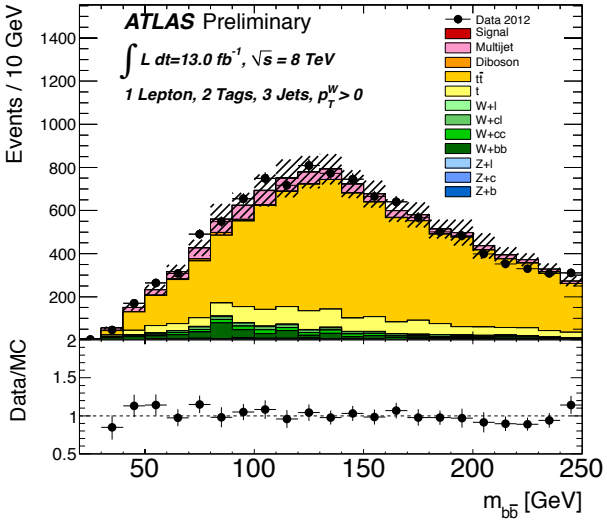
W+light: before b-tagging



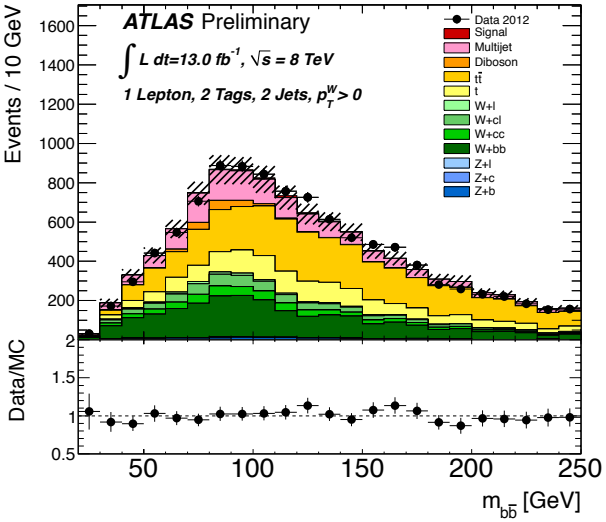
W+c: 1 b-tag



tt: 2 b-tags, 3 jets



W+b, tt, WH: 2 b-tags, 2 jets



Flavour Fit Results

- Determine flavour composition for VB +light/c: ML fit
  - Consistent between 7 and 8 TeV data
  - Z+c: MC generator changed
- W/Z p_T:
  - p_T spectrum in data falls more rapidly
  - W + jets: 5-10% correction in high p_T bins
  - Top: 15%
- Most important backgrounds: W+b, Z+b & Top
  - Normalization determined in profile likelihood fit

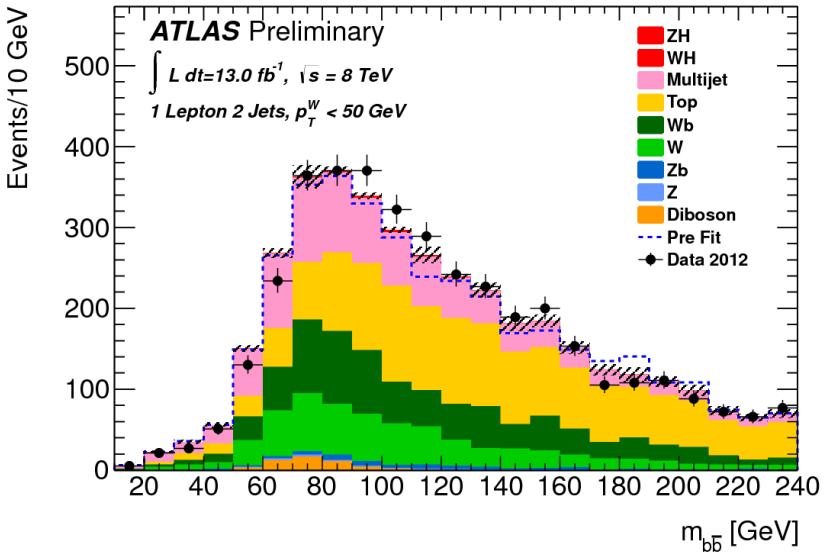
	$\sqrt{s} = 7$ TeV	$\sqrt{s} = 8$ TeV
$Z + c$	1.99 ± 0.51	0.71 ± 0.23
Z+ light	0.91 ± 0.12	0.98 ± 0.11
$W + c$	1.04 ± 0.23	1.04 ± 0.24
W+ light	1.03 ± 0.08	1.01 ± 0.14

	$\sqrt{s} = 7$ TeV	$\sqrt{s} = 8$ TeV
Top	1.10 ± 0.14	1.29 ± 0.16
$Z + b$	1.22 ± 0.20	1.11 ± 0.15
$W + b$	1.19 ± 0.23	0.79 ± 0.20

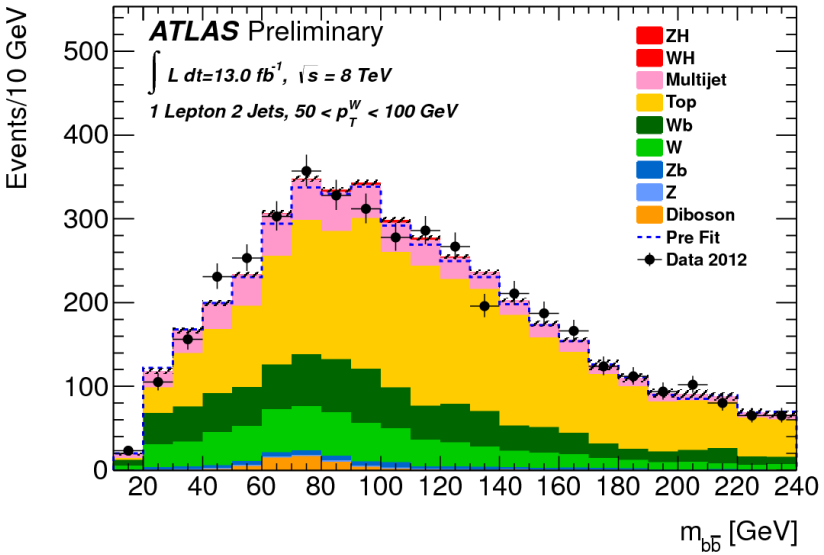
Final Invariant Mass Distributions

1 Lepton

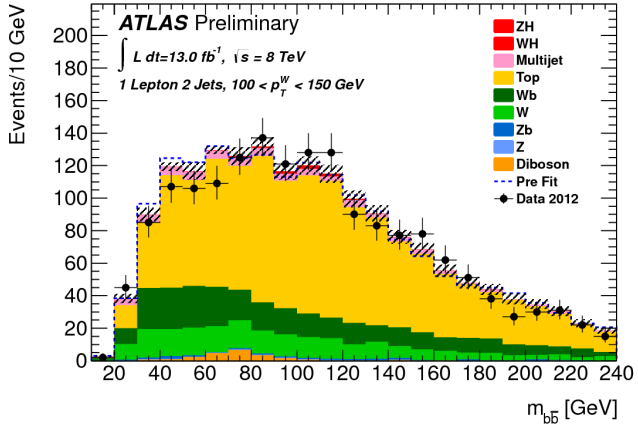
$p_T^W < 50$ GeV



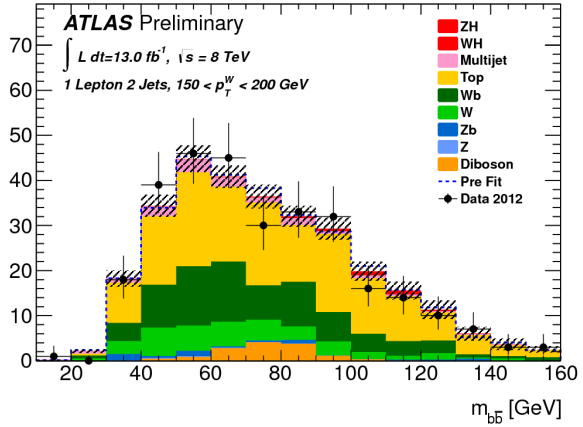
$50 < p_T^W < 100$ GeV



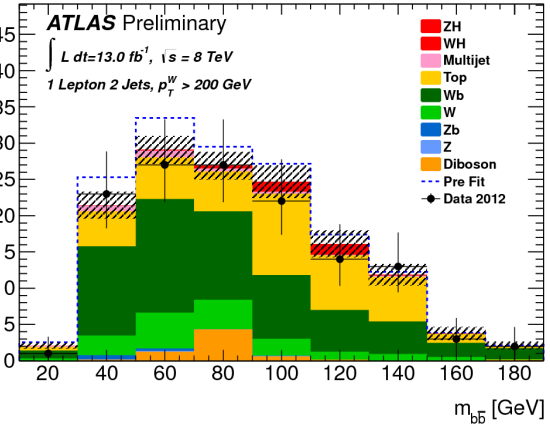
$100 < p_T^W < 150$ GeV



$150 < p_T^W < 200$ GeV

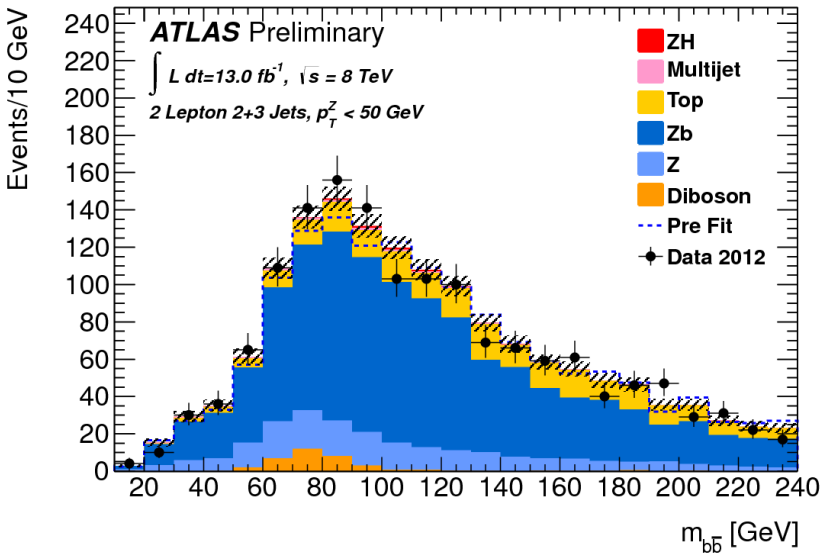


$p_T^W > 200$ GeV

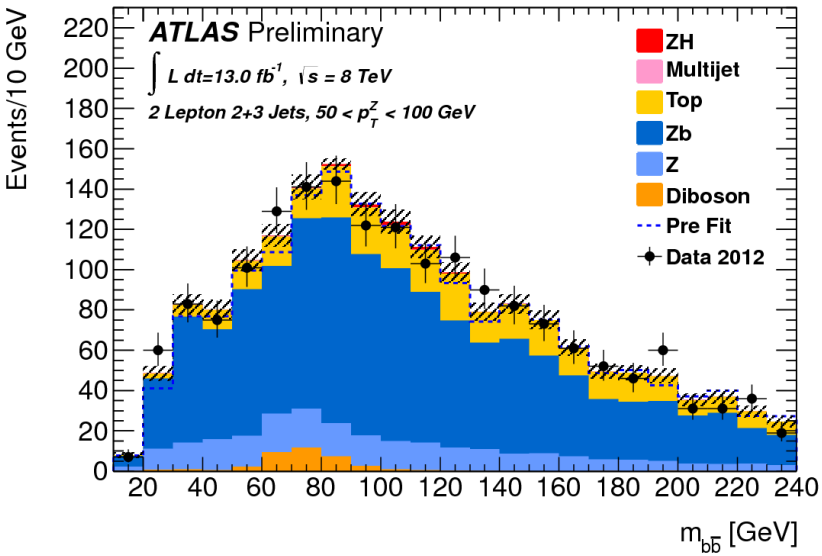


Final Invariant Mass Distributions
2 Leptons

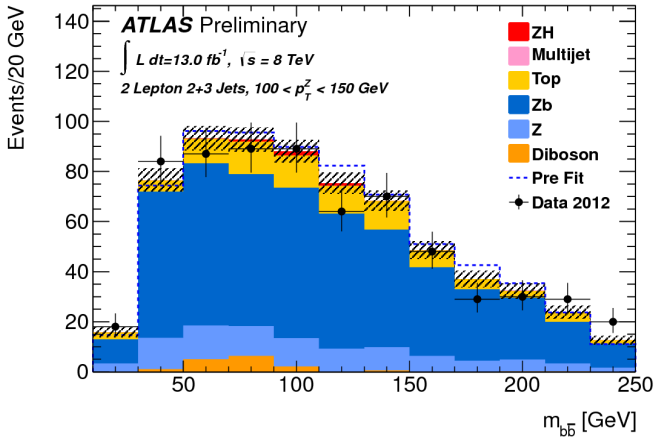
$p_T^W < 50$ GeV



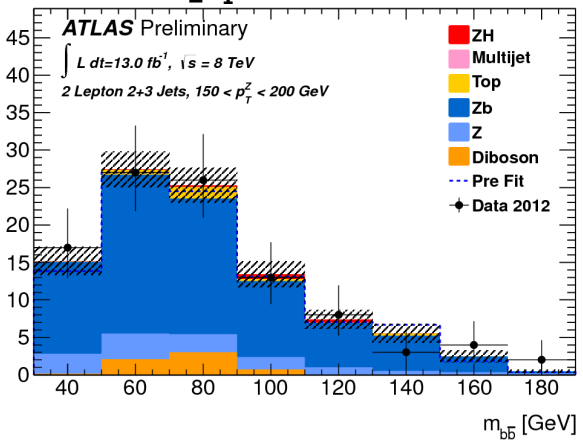
$50 < p_T^W < 100$ GeV



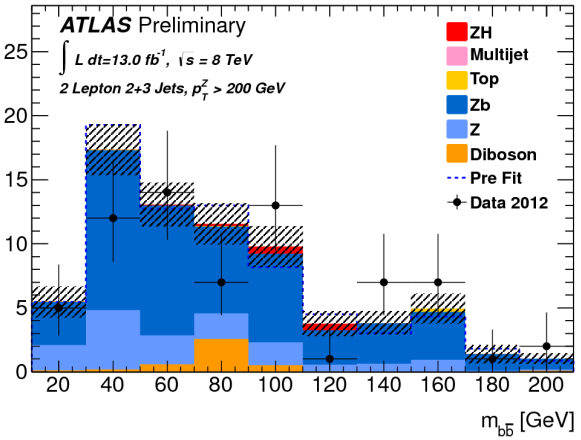
$100 < p_T^W < 150$ GeV



$150 < p_T^W < 200$ GeV

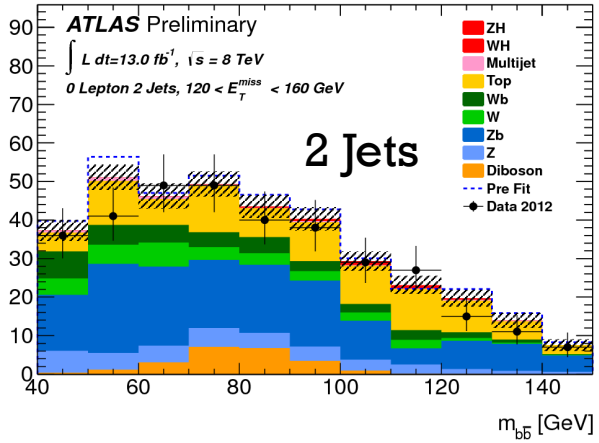


$p_T^W > 200$ GeV

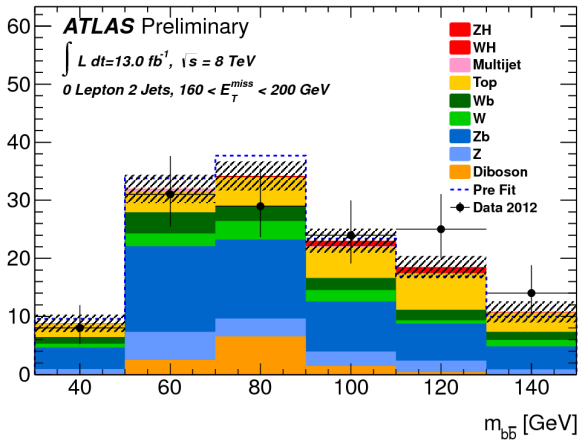


Final Invariant Mass Distributions
0 Leptons

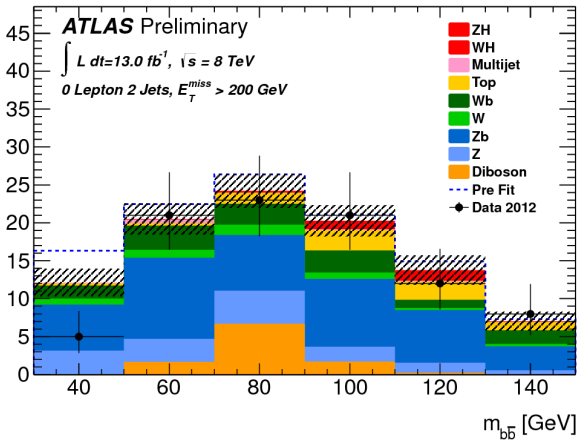
120 < MET < 160 GeV

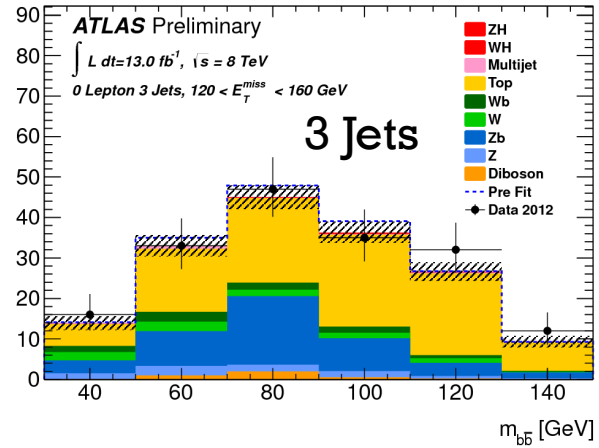


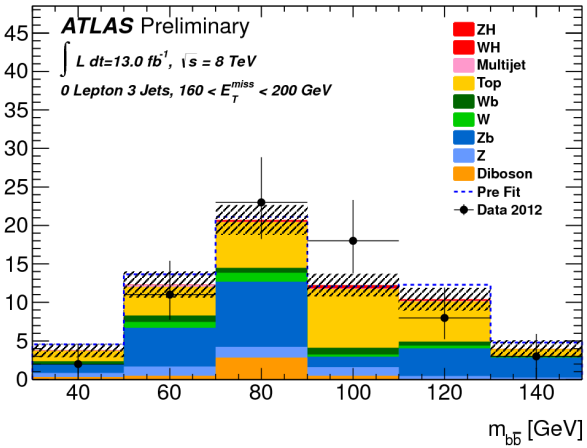
160 < MET < 200 GeV

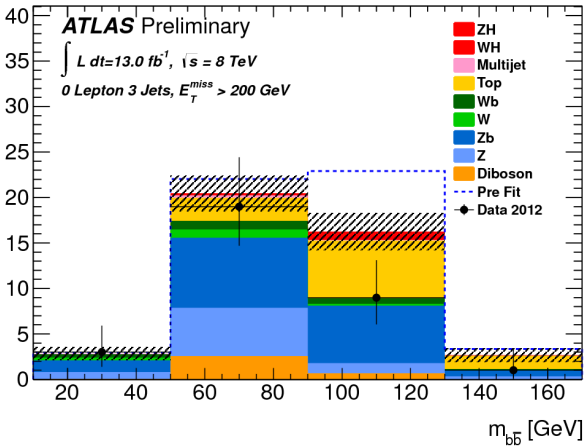


MET > 200 GeV









Systematic Uncertainties

- Main experimental uncertainties
  - **Jets** (7 JES, 1 p_T^{Reco}, resol.)
  - MET: scale and resolution
  - **b-tagging**: light, c & 6 p_T efficiency bins
  - Top, W, Z: background modelling
  - **MC statistics**
- Main theoretical uncertainties
  - m_{bb} spectrum
  - p_T spectrum of VB
  - BR(H→bb)
  - Signal cross sections
  - Single top/top normalisation
  - W+c, Z+c cross sections

Background

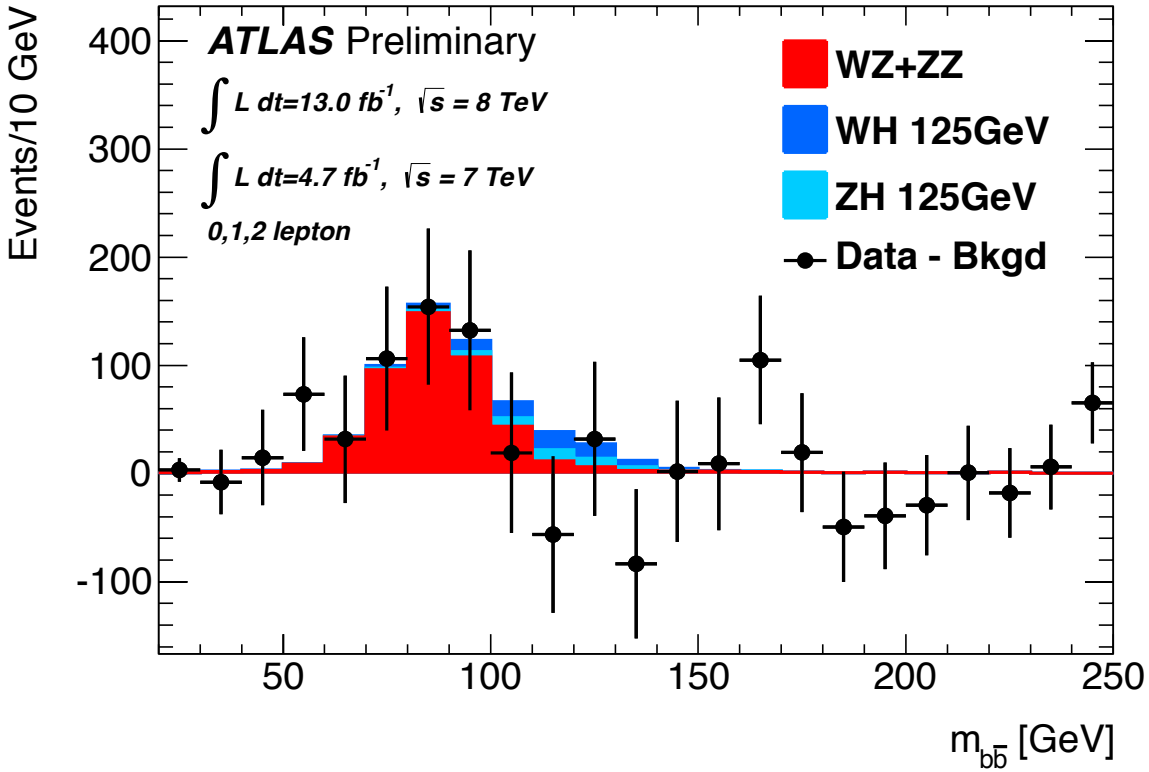
Uncertainty [%]	0 lepton	1 lepton	2 leptons
b-tagging	6.5	6.0	6.9
c-tagging	7.3	6.4	3.6
light tagging	2.1	2.2	2.8
Jet/Pile-up/E_T^{miss}	20	7.0	5.4
Lepton	0.0	2.1	1.8
Top modelling	2.7	4.1	0.5
W modelling	1.8	5.4	0.0
Z modelling	2.8	0.1	4.7
Diboson	0.8	0.3	0.5
Multijet	0.6	2.6	0.0
Luminosity	3.6	3.6	3.6
Statistical	8.3	3.6	6.6
Total	25	15	14

Signal

Uncertainty [%]	0 lepton		1 lepton	2 leptons
	ZH	*WH*	*WH*	*ZH*
b-tagging	8.9	9.0	8.8	8.6
Jet/Pile-up/E_T^{miss}	19	25	6.7	4.2
Lepton	0.0	0.0	2.1	1.8
$H \to bb$ BR	3.3	3.3	3.3	3.3
VH p_T-dependence	5.3	8.1	7.6	5.0
VH theory PDF	3.5	3.5	3.5	3.5
VH theory scale	1.6	0.4	0.4	1.6
Statistical	4.9	18	4.1	2.6
Luminosity	3.6	3.6	3.6	3.6
Total	24	34	16	13

Diboson Analysis

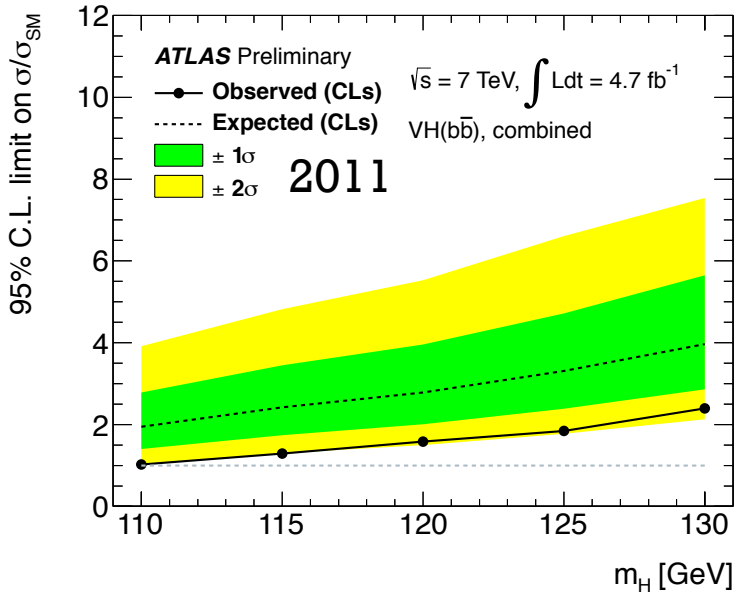
- Simple cross check of H→bb analysis
  - WZ→lvbb & ZZ→llbb / vvbb: same final state
  - Cross section 5x larger
  - Same search strategy, separate profile likelihood fit, not separated in p_T bins
- Here: All backgrounds subtracted
- Results:
  - Significance: 4.0σ
  - μ = 1.09 ± 0.20 (stat) ± 0.22 (syst)

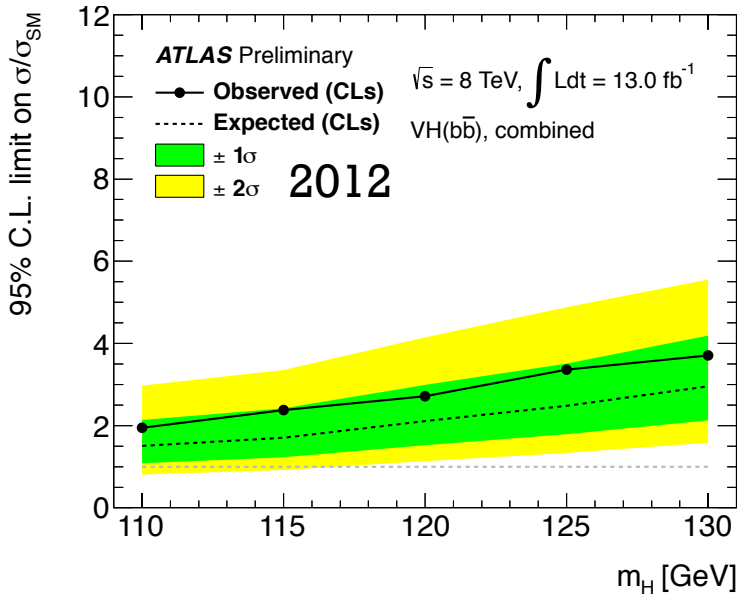


CL_s Limits: Combination of Channels

- Binned profile likelihood fit to 16 signal regions and top control regions
  - Main backgrounds W+b, Z+b and top floating
  - Likelihood $L(\mu,\theta)$
    μ: signal strength ($= \sigma/\sigma_{SM}$)
    θ: nuisance parameters for systematic uncertainties
- Results at $m_H = 125$ GeV
  - Observed (expected) limits

    2011: 1.8 (3.3) 2012: 3.4 (2.5)





CL_s Limits: Combination of Channels

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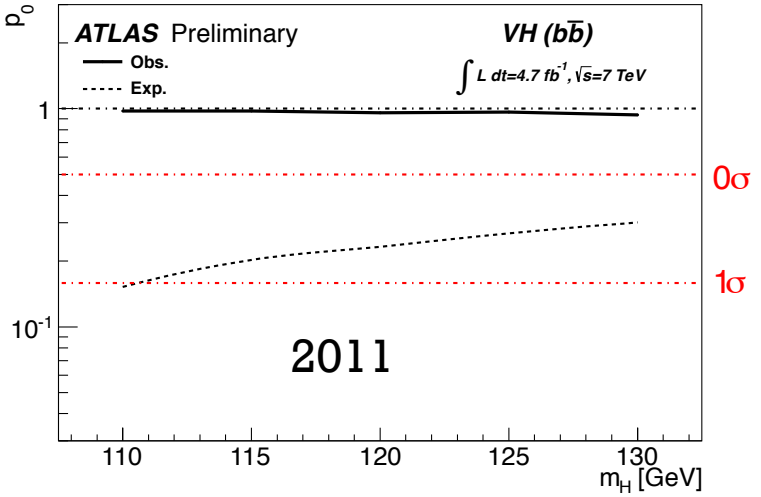
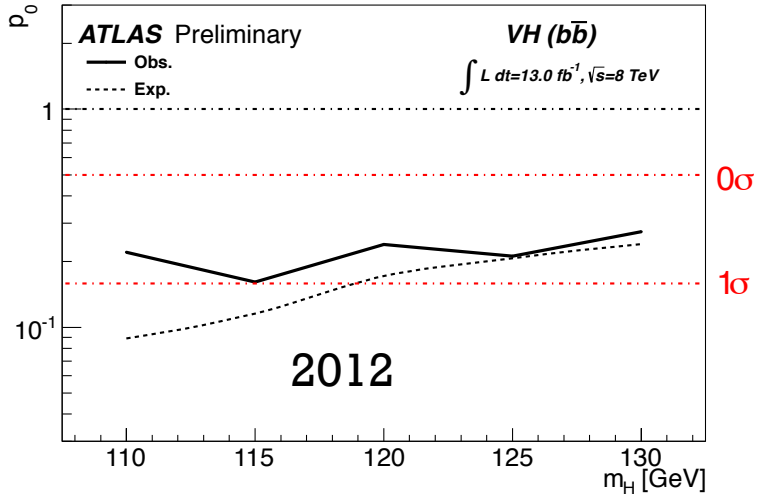
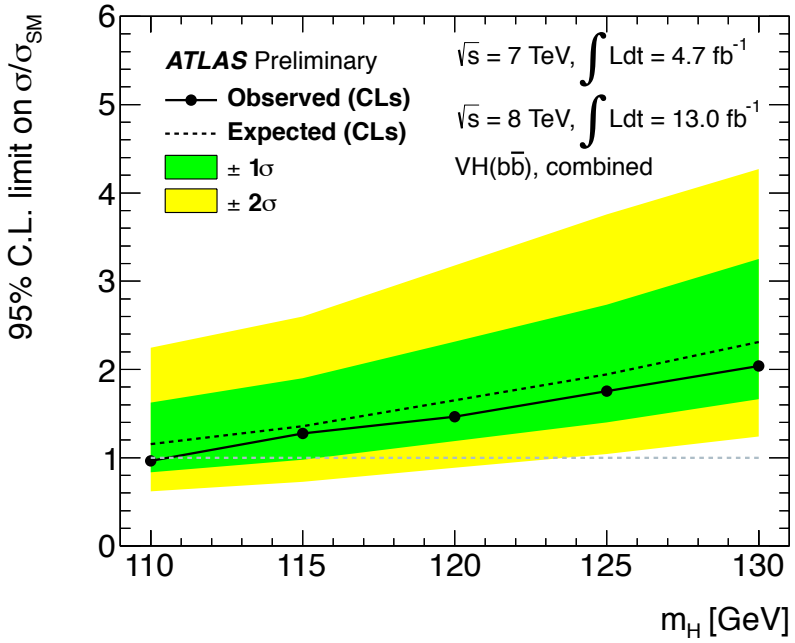
  - Main backgrounds W+b, Z+b and top floating
  - Likelihood $L(\mu,\theta)$
    μ: signal strength ($= \sigma/\sigma_{SM}$)
    θ: nuisance parameters for systematic uncertainties

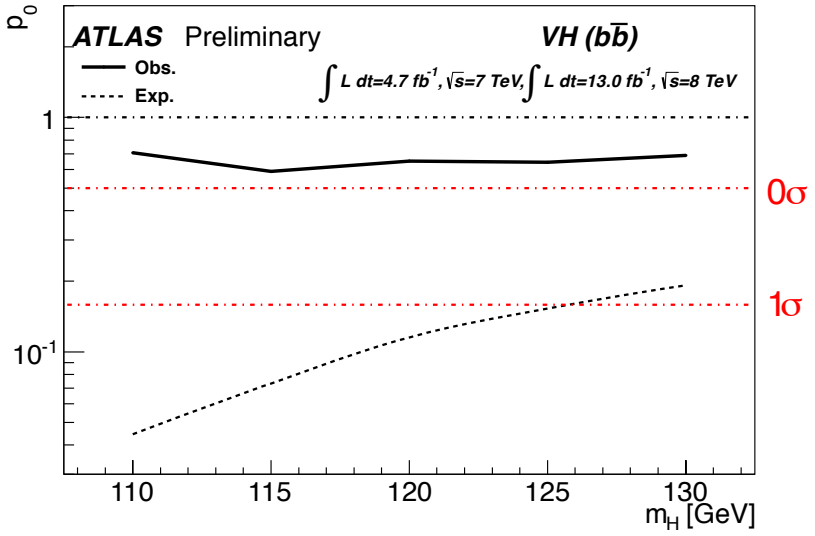
- Results at $m_H = 125$ GeV
  - Observed (expected) limits
    2011: 1.8 (3.3) 2012: 3.4 (2.5)
  - Background-only probability p_0
    2011: 0.97 (0.26) 2012: 0.17 (0.20)
  - Signal strength:
    2011: -2.7±1.1±1.1 2012: 1.0±0.9±1.1





Combination of 2011 & 2012





- Combination of 2011 and 2012, m_H = 125 GeV
  - Limit: 1.8 (1.9) x SM prediction
  - p_0: 0.64 (0.15)
  - μ: -0.4 ± 0.7 (stat) ± 0.8 (syst)

Comparison to CMS: Search Strategy

ATLAS

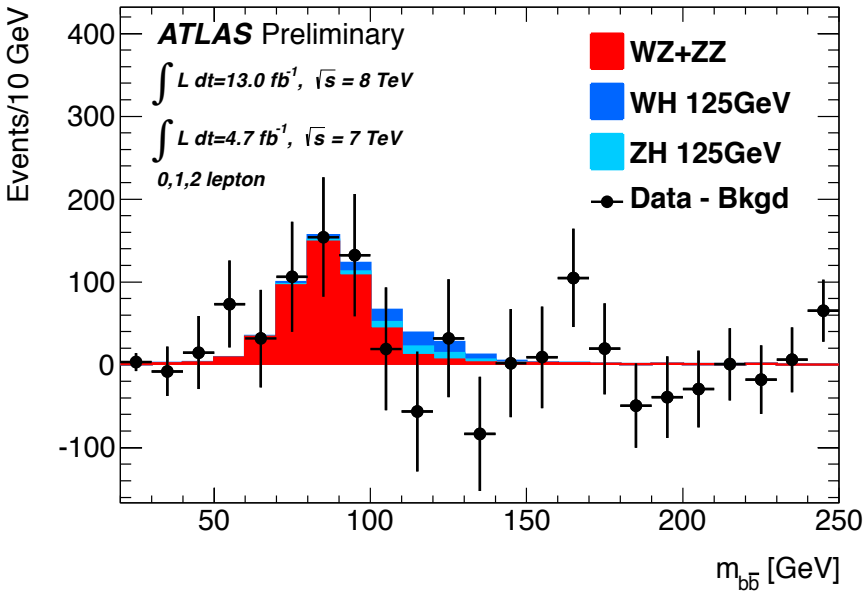
- Associated production with VB
- 3 channels: 0,1,2 leptons (e,μ)
- Search for excess in invariant mass of 2 b-jets
- Cut analysis
- 5 categories in p_T^V: 0 - >200 GeV
- Correction of semileptonic muon decays in jets

CMS-PAS-HIG-12-044

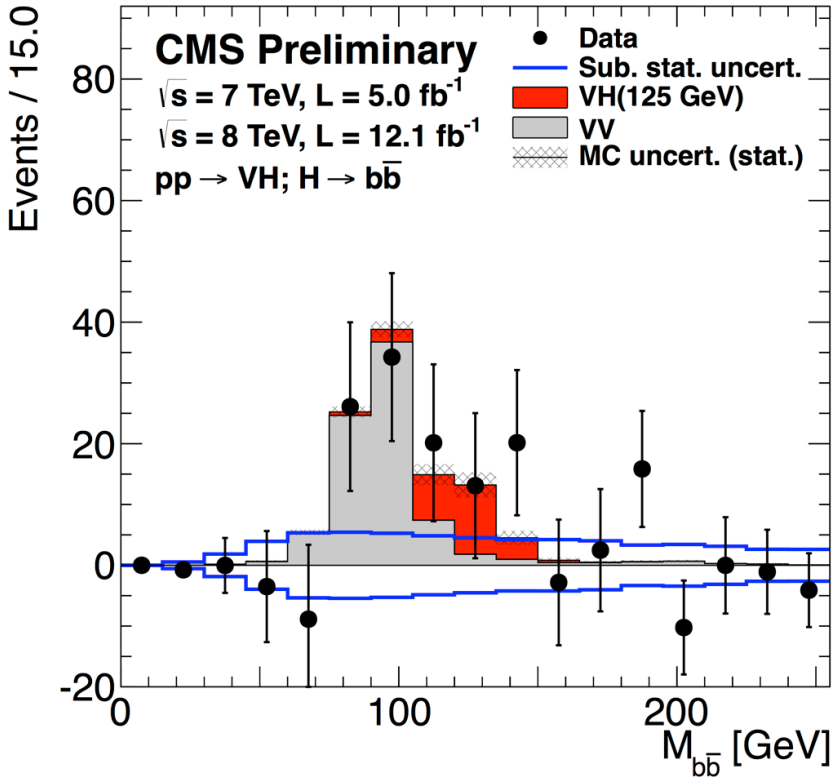
- Associated production with VB
- 3 channels: 0,1,2 leptons (e,μ)
- Search for excess in invariant mass of 2 b-jets
- Boosted decision trees (BDT)
- 2 categories in p_T^V: 120-170, >170 GeV (WH)
- Multivariate regression to improve mass resolution

Comparison to CMS: DiBoson

ATLAS

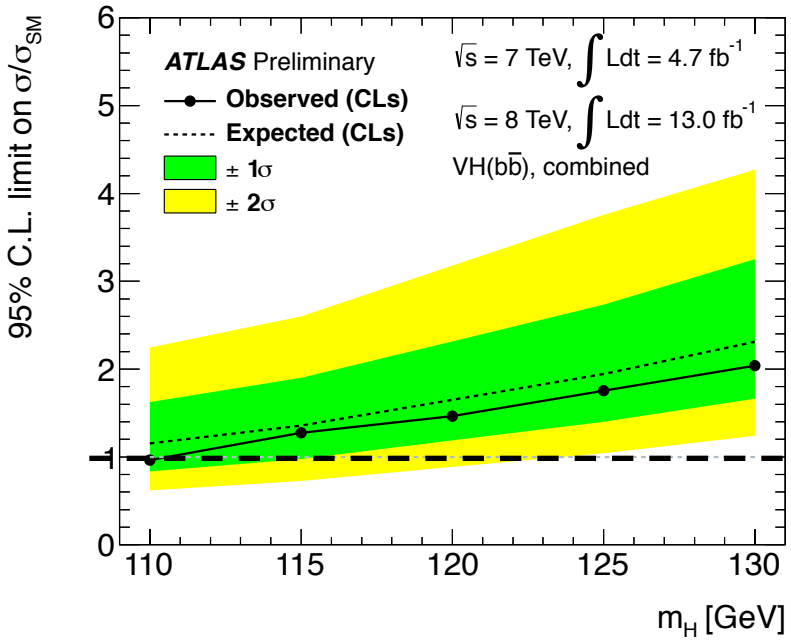


CMS-PAS-HIG-12-044

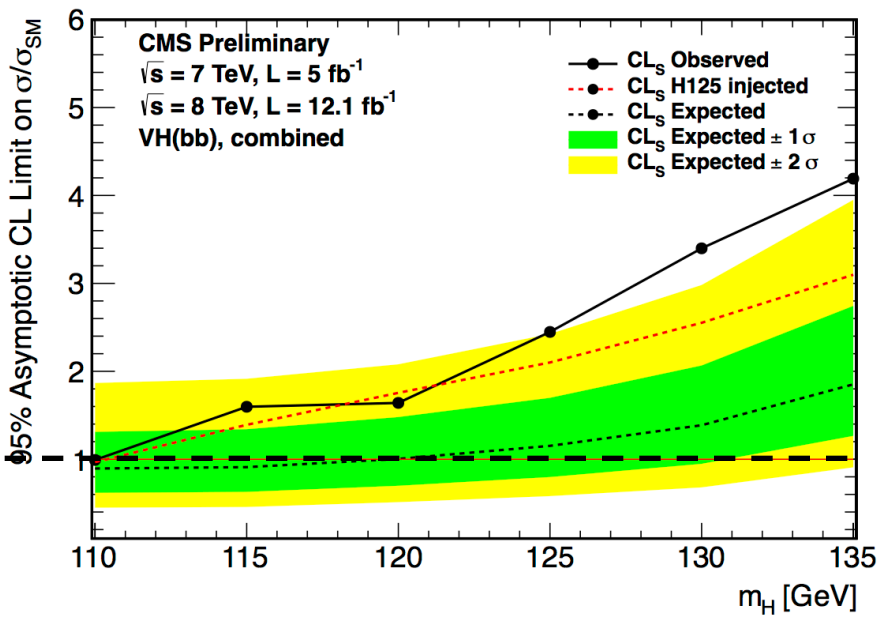


Comparison to CMS: Limits

ATLAS

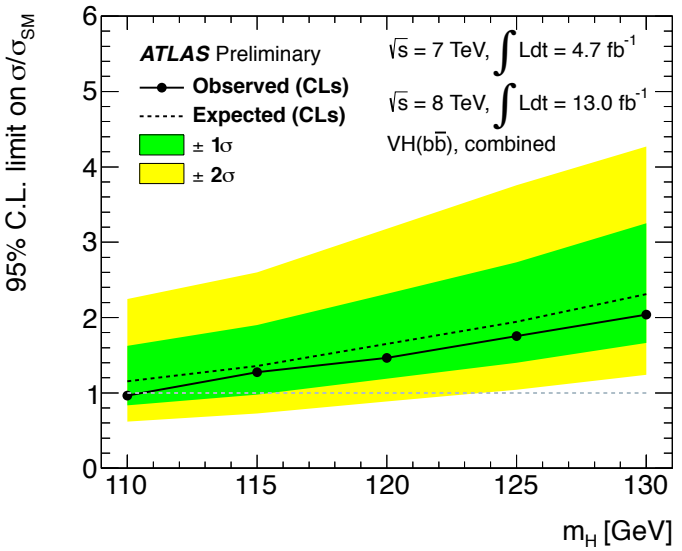


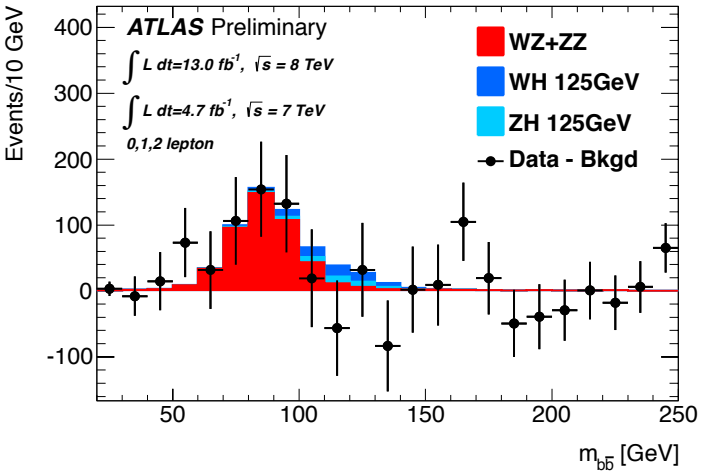
CMS-PAS-HIG-12-044



Summary

- First combined 2011/2012 analysis in H → bb channel
  - Improvements in sensitivity
  - 2σ deficit in 2011, 1σ excess in 2012 data
- Observed (expected) limit: 1.8 (1.9) at m_H = 125 GeV
- Clear di-Boson signal (4.0σ):
  - μ = 1.09 ± 0.20 (stat) ± 0.22 (syst)
  - In agreement with SM





ATLAS-CONF-2012-161

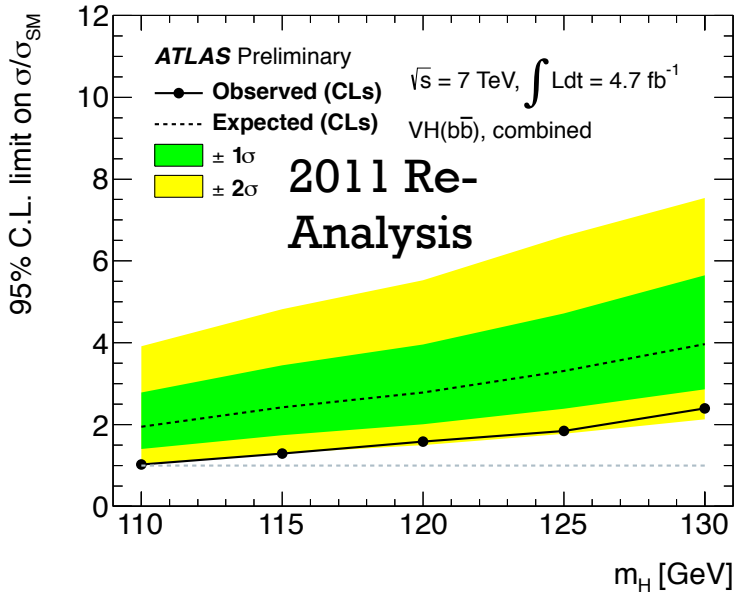
Backup

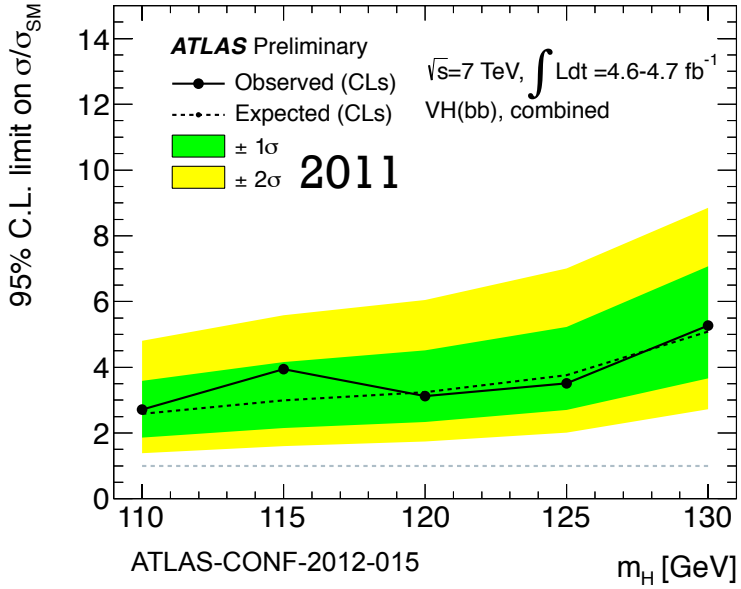
CL_s Limits: Combination of Channels

- Binned profile likelihood fit, 16 signal regions, top control regions
  - Main backgrounds W+b, Z+b and top floating
  - Likelihood $L(\mu,\theta)$
    μ: signal strength ($= \sigma/\sigma_{SM}$)
    θ: nuisance parameters for systematic uncertainties
- Comparison to previous analysis
  - Observed (expected) limits

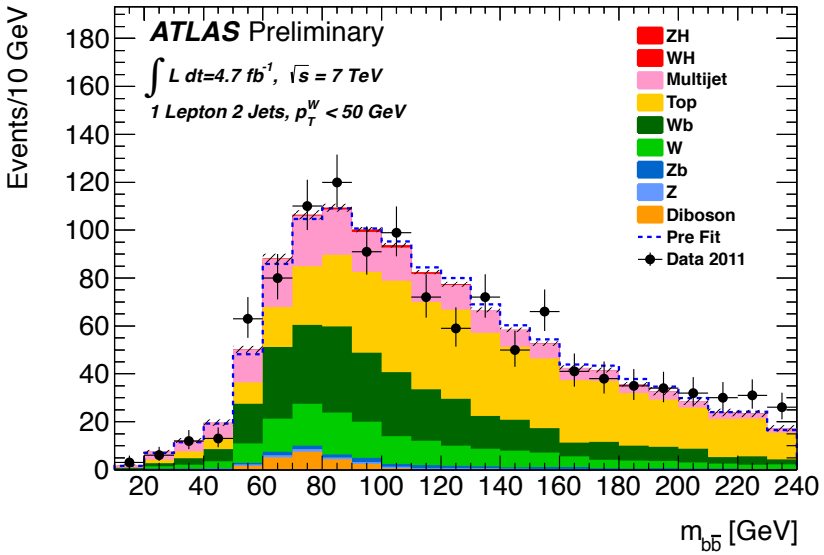
    2011: 1.8 (3.3)

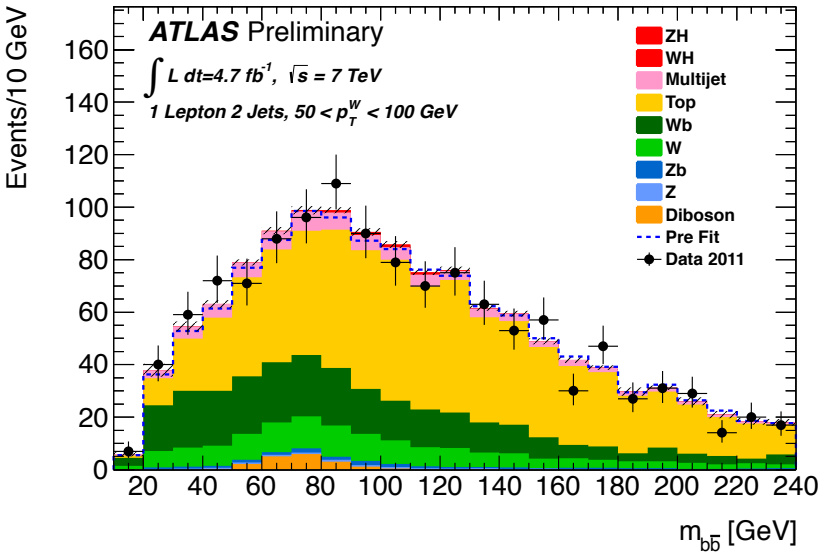
    Previous 2011: 3.5 (3.8)

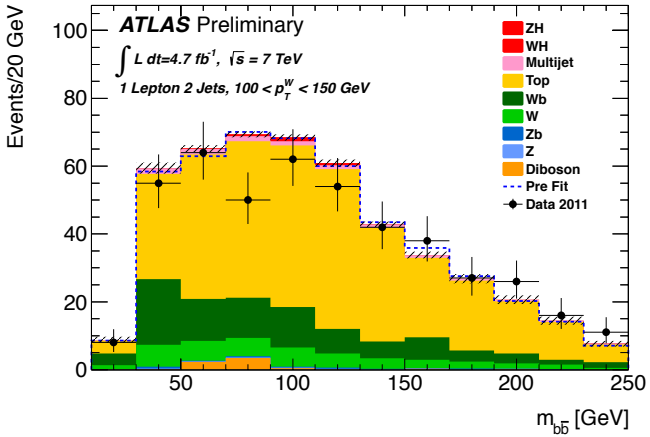


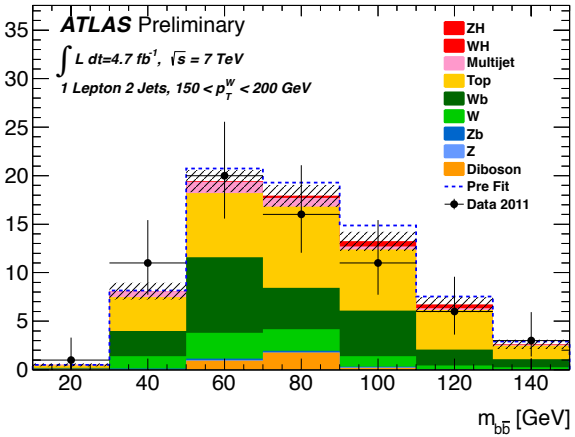


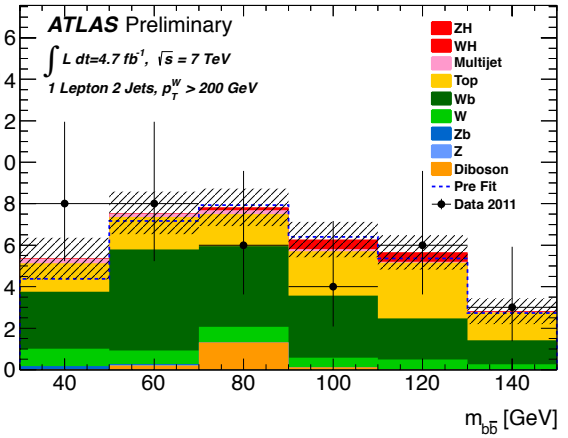
2011: WH → lνbb


ATLAS Preliminary
∫ L dt=4.7 fb⁻¹, √s = 7 TeV
1 Lepton 2 Jets, p_T^W < 50 GeV
ZH
WH
Multijet
Top
Wb
W
Zb
Z
Diboson
Pre Fit
Data 2011
Events/10 GeV
m_bb̄ [GeV]

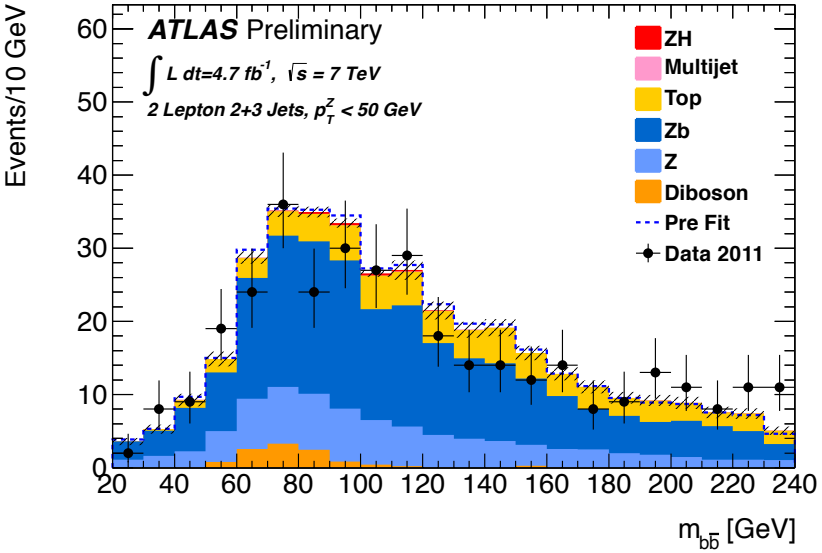

ATLAS Preliminary
∫ L dt=4.7 fb⁻¹, √s = 7 TeV
1 Lepton 2 Jets, 50 < p_T^W < 100 GeV
ZH
WH
Multijet
Top
Wb
W
Zb
Z
Diboson
Pre Fit
Data 2011
Events/10 GeV
m_bb̄ [GeV]

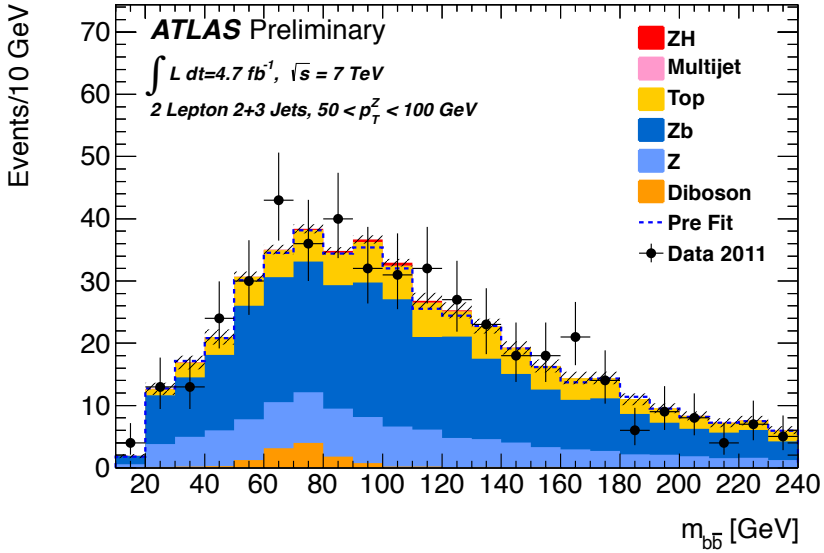

ATLAS Preliminary
∫ L dt=4.7 fb⁻¹, √s = 7 TeV
1 Lepton 2 Jets, 100 < p_T^W < 150 GeV
ZH
WH
Multijet
Top
Wb
W
Zb
Z
Diboson
Pre Fit
Data 2011
Events/20 GeV
m_bb̄ [GeV]

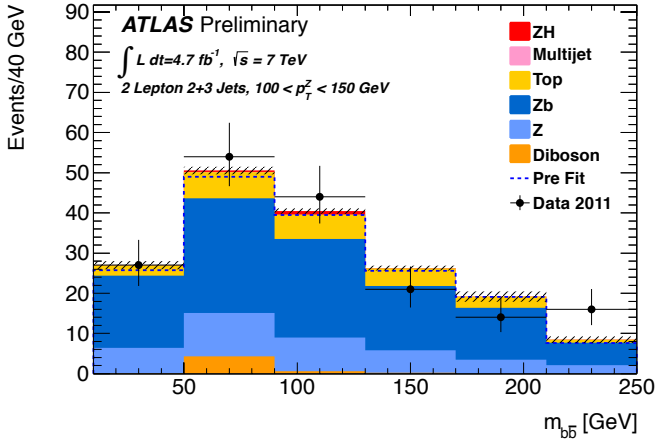

ATLAS Preliminary
∫ L dt=4.7 fb⁻¹, √s = 7 TeV
1 Lepton 2 Jets, 150 < p_T^W < 200 GeV
ZH
WH
Multijet
Top
Wb
W
Zb
Z
Diboson
Pre Fit
Data 2011
m_bb̄ [GeV]

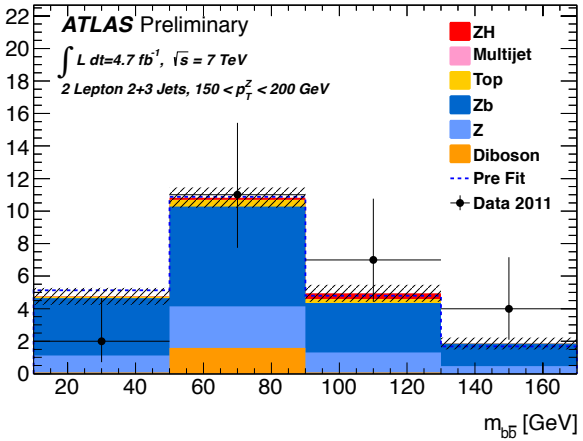

ATLAS Preliminary
∫ L dt=4.7 fb⁻¹, √s = 7 TeV
1 Lepton 2 Jets, p_T^W > 200 GeV
ZH
WH
Multijet
Top
Wb
W
Zb
Z
Diboson
Pre Fit
Data 2011
m_bb̄ [GeV]

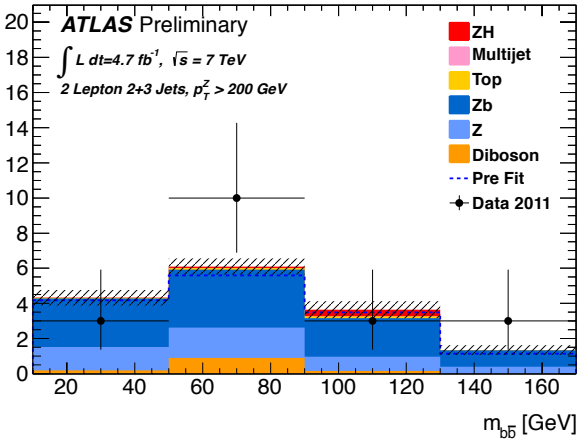
2011: ZH → llbb


ATLAS Preliminary
∫ L dt=4.7 fb⁻¹, √s = 7 TeV
2 Lepton 2+3 Jets, p_T^Z < 50 GeV
ZH
Multijet
Top
Zb
Z
Diboson
Pre Fit
Data 2011
Events/10 GeV
m_bb̄ [GeV]

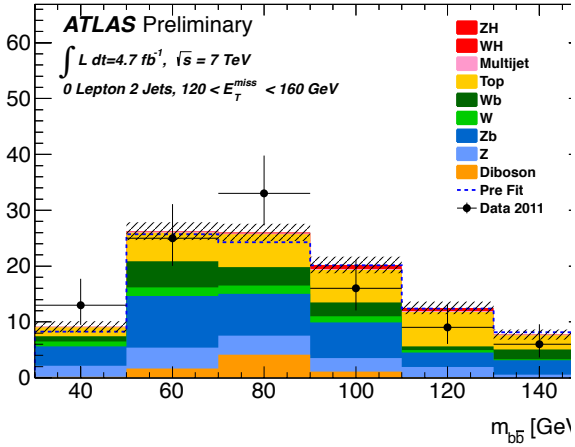

ATLAS Preliminary
∫ L dt=4.7 fb⁻¹, √s = 7 TeV
2 Lepton 2+3 Jets, 50 < p_T^Z < 100 GeV
ZH
Multijet
Top
Zb
Z
Diboson
Pre Fit
Data 2011
Events/10 GeV
m_bb̄ [GeV]

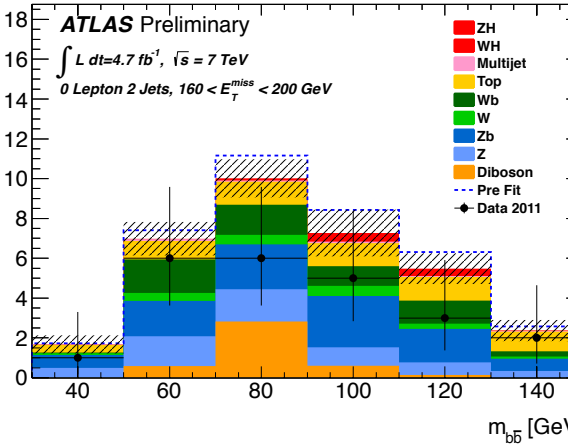

ATLAS Preliminary
∫ L dt=4.7 fb⁻¹, √s = 7 TeV
2 Lepton 2+3 Jets, 100 < p_T^Z < 150 GeV
ZH
Multijet
Top
Zb
Z
Diboson
Pre Fit
Data 2011
Events/40 GeV
m_bb̄ [GeV]

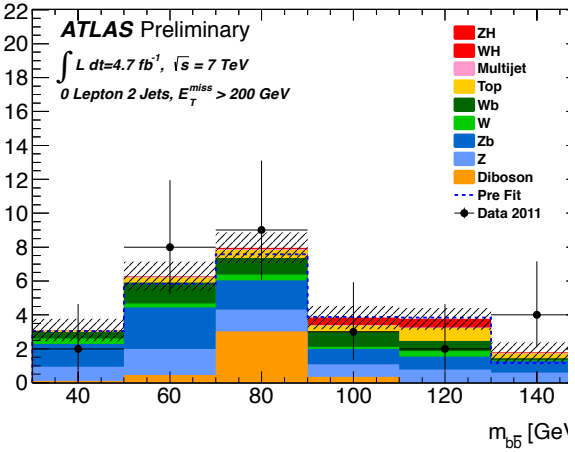

ATLAS Preliminary
∫ L dt=4.7 fb⁻¹, √s = 7 TeV
2 Lepton 2+3 Jets, 150 < p_T^Z < 200 GeV
ZH
Multijet
Top
Zb
Z
Diboson
Pre Fit
Data 2011
m_bb̄ [GeV]

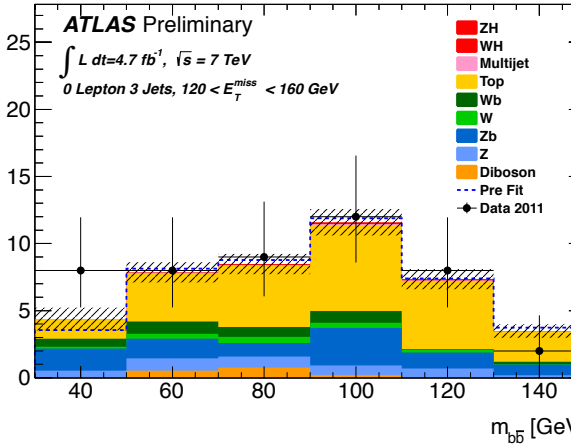

ATLAS Preliminary
∫ L dt=4.7 fb⁻¹, √s = 7 TeV
2 Lepton 2+3 Jets, p_T^Z > 200 GeV
ZH
Multijet
Top
Zb
Z
Diboson
Pre Fit
Data 2011
m_bb̄ [GeV]

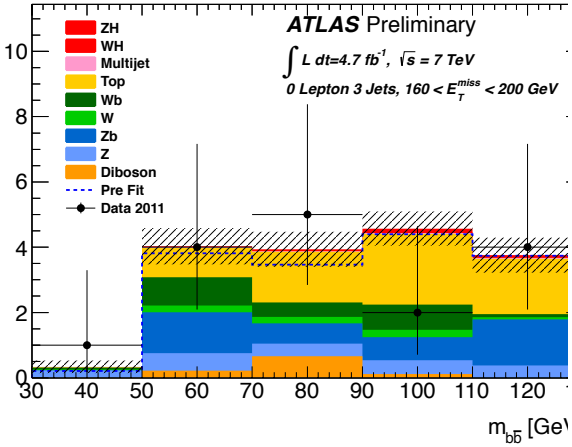
2011: ZH →vvbb

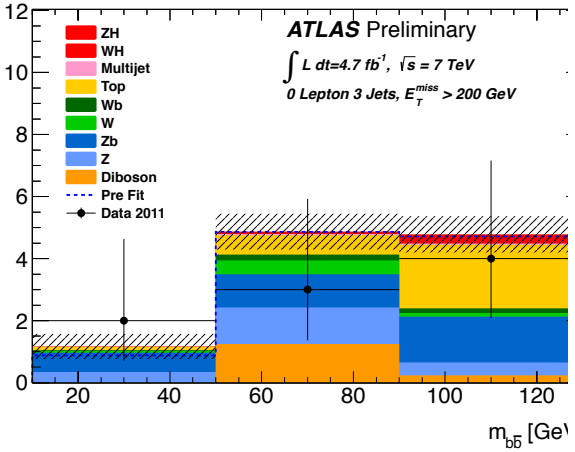

ATLAS Preliminary
∫ L dt=4.7 fb⁻¹, √s = 7 TeV
0 Lepton 2 Jets, 120 < E_T^miss < 160 GeV
ZH
WH
Multijet
Top
Wb
W
Zb
Z
Diboson
Pre Fit
Data 2011
m_bb̄ [Ge


ATLAS Preliminary
∫ L dt=4.7 fb⁻¹, √s = 7 TeV
0 Lepton 2 Jets, 160 < E_T^miss < 200 GeV
ZH
WH
Multijet
Top
Wb
W
Zb
Z
Diboson
Pre Fit
Data 2011
m_bb̄ [Ge


ATLAS Preliminary
∫ L dt=4.7 fb⁻¹, √s = 7 TeV
0 Lepton 2 Jets, E_T^miss > 200 GeV
ZH
WH
Multijet
Top
Wb
W
Zb
Z
Diboson
Pre Fit
Data 2011
m_bb̄ [Ge


ATLAS Preliminary
∫ L dt=4.7 fb⁻¹, √s = 7 TeV
0 Lepton 3 Jets, 120 < E_T^miss < 160 GeV
ZH
WH
Multijet
Top
Wb
W
Zb
Z
Diboson
Pre Fit
Data 2011
m_bb̄ [Ge


ATLAS Preliminary
∫ L dt=4.7 fb⁻¹, √s = 7 TeV
0 Lepton 3 Jets, 160 < E_T^miss < 200 GeV
ZH
WH
Multijet
Top
Wb
W
Zb
Z
Diboson
Pre Fit
Data 2011
m_bb̄ [Ge


ATLAS Preliminary
∫ L dt=4.7 fb⁻¹, √s = 7 TeV
0 Lepton 3 Jets, E_T^miss > 200 GeV
ZH
WH
Multijet
Top
Wb
W
Zb
Z
Diboson
Pre Fit
Data 2011
m_bb̄ [Ge

Event Numbers

	0-lepton, 2 jet			0-lepton, 3 jet			1-lepton					2-lepton				
Bin	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]						p_{T}^{W} [GeV]					p_{T}^{Z} [GeV]				
	120-160	160-200	>200	120-160	160-200	>200	0-50	50-100	100-150	150-200	> 200	0-50	50-100	100-150	150-200	>200
ZH	2.9	2.1	2.6	0.8	0.8	1.1	0.3	0.4	0.1	0.0	0.0	4.7	6.8	4.0	1.5	1.4
WH	0.8	0.4	0.4	0.2	0.2	0.2	10.6	12.9	7.5	3.6	3.6	0.0	0.0	0.0	0.0	0.0
Top	89	25	8	92	25	10	1440	2276	1120	147	43	230	310	84	3	0
$W + c$,light	30	10	5	9	3	2	580	585	209	36	17	0	0	0	0	0
$W + b$	35	13	13	8	3	2	770	778	288	77	64	0	0	0	0	0
$Z + c$,light	35	14	14	8	5	8	17	17	4	1	0	201	230	91	12	15
$Z + b$	144	51	43	41	22	16	50	63	13	5	1	1010	1180	469	75	51
Diboson	23	11	10	4	4	3	53	59	23	13	7	37	39	16	6	4
Multijet	3	1	1	1	1	0	890	522	68	14	3	12	3	0	0	0
Total Bkg.	361	127	98	164	63	42	3810	4310	1730	297	138	1500	1770	665	97	72
	± 29	± 11	± 12	± 13	± 8	± 5	± 150	± 86	± 90	± 27	± 14	± 90	± 110	± 47	± 12	± 12
Data	342	131	90	175	65	32	3821	4301	1697	297	132	1485	1773	657	100	69

Preselection cuts

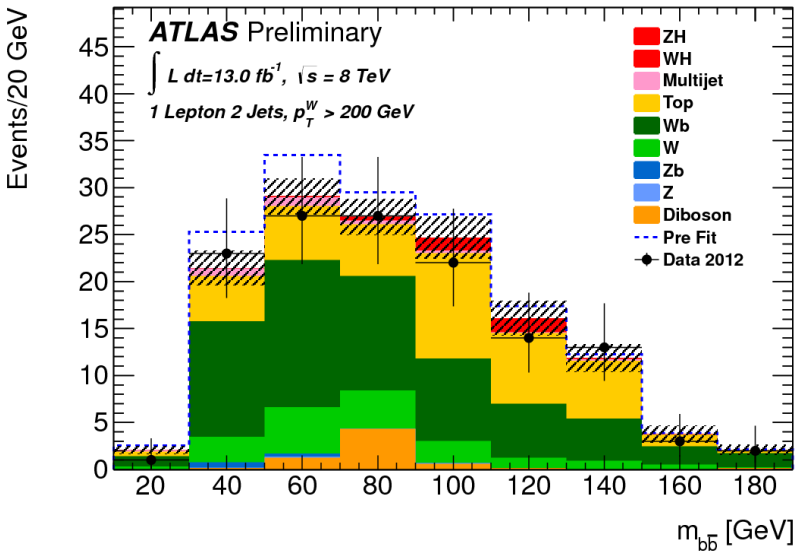
Object	0-lepton	1-lepton	2-lepton
Leptons	0 loose leptons	1 tight lepton + 0 loose leptons	1 medium lepton + 1 loose lepton
Jets	2 b-tags $p_{\mathrm{T}}^{1} > 45$ GeV $p_{\mathrm{T}}^{2} > 20$ GeV + ≤ 1 extra jets	2 b-tags $p_{\mathrm{T}}^{1} > 45$ GeV $p_{\mathrm{T}}^{2} > 20$ GeV + 0 extra jets	2 b-tags $p_{\mathrm{T}}^{1} > 45$ GeV $p_{\mathrm{T}}^{2} > 20$ GeV -
Missing E_T	$E_{\mathrm{T}}^{\mathrm{miss}} > 120$ GeV $p_{\mathrm{T}}^{\mathrm{miss}} > 30$ GeV $\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, p_{\mathrm{T}}^{\mathrm{miss}}) < \pi/2$ $\mathrm{Min}[\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, \mathrm{jet})] > 1.5$ $\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, b\bar{b}) > 2.8$	-	$E_{\mathrm{T}}^{\mathrm{miss}} < 60$ GeV
Vector Boson	-	$m_{\mathrm{T}}^{W} < 120$ GeV	$83 < m_{\ell\ell} < 99$ GeV

Topological Cuts

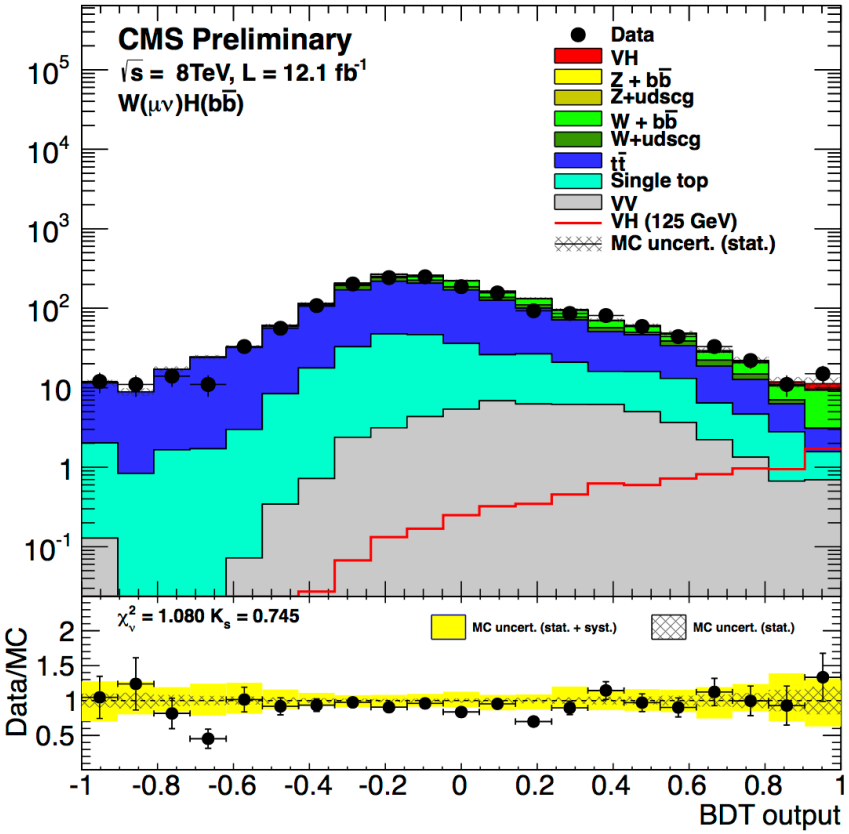
0-lepton channel					
$E_{\mathrm{T}}^{\mathrm{miss}}$ (GeV)	120-160		160-200		>200
$\Delta R(b,\bar{b})$	0.7-1.9		0.7-1.7		<1.5
1-lepton channel					
p_{T}^{W} (GeV)	0-50	50-100	100-150	150-200	>200
$\Delta R(b,\bar{b})$	>0.7			0.7-1.6	<1.4
$E_{\mathrm{T}}^{\mathrm{miss}}$ (GeV)	> 25				> 50
m_{T}^{W} (GeV)	> 40			-	
2-lepton channel					
p_{T}^{Z} (GeV)	0-50	50-100	100-150	150-200	>200
$\Delta R(b,\bar{b})$	>0.7			0.7-1.8	<1.6

Comparison to CMS

ATLAS



CMS (CMS-PAS-HIG-12-044)



Multijet Estimate

- 0 lepton
  - Use ABCD method
  - Regions defined by relative directions of MET/jets/pTmiss
  - Found to be small (~1%)
- 1 lepton
  - MET template by reverse isolation cuts
  - Normalised by fitting each WpT bin
  - Electroweak contamination removed from template
- 2 lepton
  - Template: reverse isolation/quality selection
  - Found to be small (<1%)

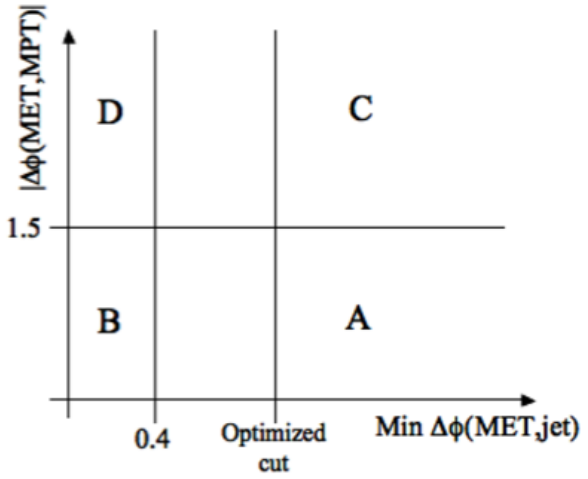
ABCD method

Use lack of correlation

Δϕ (Etmiss,pTmiss) vs

Δϕ (Etmiss,jets)

for multi-jet background estimation in signal region



$$N_{QCD}(A) = \frac{N(B)}{N(D)} \times N(C)$$

From Phil Clark's talk at HCP

p_T Spectrum of VB